

A NEW APPROACH TO GEOPHYSICAL SURVEYING FOR UXO: NEW LEVELS OF EFFICIENCY, PRODUCTIVITY, AND DATA QUALITY

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1.0 Abstract

The wide diversity of UXO site conditions and the variable type and spatial distribution of buried UXO make geophysical mapping a complicated task. UXO mapping jobs can range from 20-mm rounds near the surface to large bombs tens of meters in depth. Furthermore, site conditions range from flat and open, to swampy lowlands and wooded hillsides. As such, the use of geophysical technologies as a primary characterization approach must be flexible enough to safely handle all conditions. SC&A has developed a suite of field characterization technologies specifically designed with the broad spectrum of UXO activities in mind. No longer limited to “golf course” conditions, these digital technologies can be deployed at a wide array of sites where UXO are located. SC&A’s field data acquisition technology is based on a GPS-integrated, man-portable cart system, and is augmented with a backpack configuration. This technology, referred to as the Flexible Array Survey Technology (FAST) has been field proven with magnetometers, gradiometers, time-domain electromagnetic, and frequency-domain electromagnetic sensors. The FAST cart system generates essentially noise-free data, as the deployment platform is constructed of composite materials. In the magnetometer mode, the system has been proven to routinely collect data from 40-50 acres per day. More importantly, the system design allows the productivity to be scaled up to virtually any practical level using commercial off-the-shelf (COTS) sensor and navigation components. SC&A’s automated UXO Target Analysis Software System is integrated within a comprehensive geographical information system (GIS) and automatically processes data from any of the field sensors. This cart-based FAST method was specifically designed to keep UXO-qualified personnel in the loop as operators of the equipment; keeping the people best qualified to work safely on UXO sites directly involved in the work.

2.0 Introduction

Within the UXO clearance industry a need exists for new geophysical survey technologies that are reliable, flexible, accurate, and efficient. This requirement is driven by the current trend to replace traditional manual, analog, audio detection methods (referred to as “mag and flag”) with digital geophysical surveys.

SC&A reviewed the technical, logistical, and financial issues associated with UXO surveying and developed a new strategy for field deployment methodologies. This paper describes the parameters that influence the design of effective geophysical survey technologies and provides a working example of a system that utilizes this new approach.

3.0 Requirements for Effective Surveying

The following technical issues must be considered when developing effective and efficient UXO geophysical survey technologies:

- Data Quality
- Sensor Deployment Flexibility
- Navigation Technology
- Productivity Rates
- Safety
- Integrated Data Analysis

3.1 Data Quality

In order to detect UXO, sensor readings must be made such that the signal associated with the UXO is strong enough to be seen in the data. This obvious requirement imparts several central design constraints on practical deployment technologies. First, the sensor reading (from magnetometers, gradiometers, electromagnetic devices, etc.) must have amplitudes greater than background noise levels. This factor is generally referred to as the signal to noise ratio (SNR). The SNR can be optimized in two fundamental ways; a) record the strongest possible UXO-related signatures, and b) minimize the noise levels.

To collect the best possible SNR of geophysical data at UXO sites, the sensors need to be positioned as close to the target as possible. The common use of magnetometers and time-domain electromagnetic sensors has shown that the best success is achieved when the sensors are close to the ground. Furthermore, the collection of data from a survey platform free of system noise is essential. Often, the signature from UXO is extremely faint, and the smallest component of noise generated from steel or metal platforms, from tow vehicles, or from system electronics in close proximity to the sensors can corrupt the data to the point where only “obvious” targets are detectable. The need for noise-free geophysical data is central to the maximal clearance of contaminated sites.

The second aspect of UXO detection deals with the interpretation of signals as possible UXO. This can be optimized by ensuring that each UXO signature is collected with sufficient fidelity and spatial density to be recognized as possible UXO. As the UXO application can range from the detection of small items such as 20-mm rounds near the surface, to 2000 lb. bombs at great depths, data density requirements vary as a function of

the suspected UXO. Thus, an optimal system must be configurable to the type and distribution of expected UXO.

From these data quality issues, it is concluded that development of a field system must include a low noise, sensor-configurable, ground-based deployment platform.

3.2 Sensor Deployment Flexibility

Each UXO site imposes different sensor requirements for peak detection and characterization performance. As noted above, the size, composition, distribution, and orientation of UXO at a site dictates the strength of the signature recorded on the field instruments. Additionally, soil and geological conditions impart various types of complicating components to the data. For example, in many cases ferromagnetic constituents of the soil cause severe distortions on magnetometer data. In other cases, the small size or great depth of expected UXO makes electromagnetic systems ineffectual.

For these reasons (the variability of UXO distribution, UXO type, and local soil conditions) an effective UXO survey system must be flexible to both sensor selection and sensor configuration.

In addition to the sensor aspect of system flexibility, an effective system must be flexible in terms of productivity. Sites can range from isolated 100-ft by 100-ft sampling parcels, to large contiguous sites several thousand acres in extent. This aspect of an optimal system design is discussed in Section 3.4.

Finally, sensor deployment flexibility must include the possibility that new and improved sensor technologies will become available. As the focus on the UXO problem intensifies, new field-proven sensors will become available that will require immediate integration.

3.3 Navigation Technology

At ordnance sites the objective of geophysical surveys is to find possible UXO. Clearly, this activity is only successful if the data are accurately positioned, and the location of the targets can be reacquired in the field. This self evident requirement forces data acquisition systems to possess integrated, highly accurate, robust, and repeatable navigation technologies. As with the sensor component of a system, the navigation component of the system must be adaptable to local site conditions.

The advent of affordable commercial off the shelf global positioning systems (GPS) has been heavily utilized to successfully position geophysical data. However, the performance specifications of GPS technologies are highly variable, and depend on: a) the type equipment utilized; b) the type of differential corrections applied to the data; c) the algorithms used to determine spatial coordinates; d) the frequency and data-type of

satellite-transmitted information; e) the satellite constellation geometry during data acquisition, and f) the line-of-site visibility of available satellites.

The large number of parameters that affect the quality of GPS data make GPS inherently problematic for non-expert users. Furthermore, at many UXO sites GPS is not practical due to the issues stated above, and must be augmented with other technologies.

For these reasons, an effective geophysical survey system must allow for the use of various navigation technologies, including, but not limited to, GPS, acoustic ranging systems, tick wheels, etc.

As with the sensor component of an optimal system, the design must allow introduction of new positioning technologies as they become available.

3.4 Productivity Rates

An effective geophysical survey system cannot be designed for a single site, but must be applicable to a wide variety of sites. UXO sites that require survey technologies range from small, quarter-acre parcels used for Engineering Evaluations / Cost Assessments (EE/CAs), to large surveys, several-thousand acres in extent, conducted as part of geophysical screening and/or remediation activities. For this reason, a deployment system must be scalable from small to large productivity rates.

A survey system is only valuable if it is actually used on a site. This simple fact requires that the system produce results at a low unit cost. In the highly cost-competitive environmental services industry, it is essential for technologies to be utilized on both small sites (less than 20 acres) and on large sites (greater than 1,000 acres).

In addition to the need for deployment flexibility for different sized sites, a useful technology will be able to be deployed at several sites simultaneously. Development of technologies that can be mass produced, using COTS technologies, and yielding fully scalable survey production capabilities, will shift the limiting factor in performing clearance work from the UXO industry's capacity to perform work, to the government's desire to clear large areas.

The strategy to develop mass-producible deployment technologies has the added benefit of allowing redundant survey gear to be provided at all sites, reducing downtime delays to negligible levels.

3.5 Safety

The goal of detecting, locating, and characterizing buried UXO is only successful if performed in a safe manner. Highly productive, low-noise, flexible survey systems will be ineffectual if designed without adequate safety features. Ideally, a survey technology

should be operable by qualified UXO professionals, who bring the wealth of knowledge related to UXO field operations to the job.

In terms of design, an optimal system should allow the operator to stop deployment as visible surface UXO, or other suspect objects, are encountered.

3.6 Integrated Data Analysis

In order to be effective, the collection of digital geophysical data at UXO sites must be complemented with a data analysis system that can process all collected data, track the high volume of information generated during an operation, and provide the means to detect, locate, and characterize UXO. The data analysis system must be robust enough to handle changing conditions from site to site, and be operated within a standard operating procedure that allows for quality control functions.

Additionally, a fully integrated analysis system should allow concurrent use of various non-geophysical sources of information, including aerial photographs, prior land use data, planimetric data, soil maps, etc. An optimal data analysis system should be fully integrated within a geographical information system (GIS).

4.0 SC&A's New Cart Based Deployment Technology

Over the last six years, SC&A has been involved in over 25 UXO site investigations that have utilized digital geophysics. Based on this experience, and based on the performance criteria described above in Section 3, SC&A developed a new geophysical survey technology specifically for UXO applications. This technology has been fully developed, tested, and deployed to seven separate UXO sites in the last year, and has been used to survey over 4,000 acres with magnetometers, gradiometers, and electromagnetic sensors.

4.1 The Flexible Array Survey Technology (FAST)

SC&A's new survey technology, referred to as the Flexible Array Survey Technology (FAST) has incorporated many of the optimal performance goals outlined in Section 3. The FAST methodology allows for collection, processing, and on-site analysis of geophysical data over various types of terrain potentially contaminated with UXO. The technology uses reliable, tested, and accepted off-the-shelf sensors and navigation components. Total field magnetometer, gradiometer, and electromagnetic configurations have been extensively utilized. All sensors are integrated with global positioning system (GPS) on a rugged cart constructed of composite materials producing essentially noise-free data. (Figure 1).



Figure 1. SC&A's cart-based magnetometer configuration. The device utilizes Trimble realtime differential GPS and total field magnetometers. The cart is made of composite materials that introduce no noise to the geophysical measurements. SC&A has built five carts that can be deployed separately or in sets, and has achieved coverage rates of over 70 acres per day fielding three carts.

Presently, the FAST system has surveyed several UXO sites utilizing magnetometer and electromagnetic sensors. Figure 2 shows representative data collected from two such deployments. In the magnetometer configuration, routine productivity rates of 40-50 acres per day have been achieved, with over 70 acres covered in one day. The scalability of the system allow for hundreds of acres to per covered per day, as larger clearance rates are needed. With electromagnetic sensors, 20 acres per day have been achieved, with equivalent production scaling factors readily achievable.

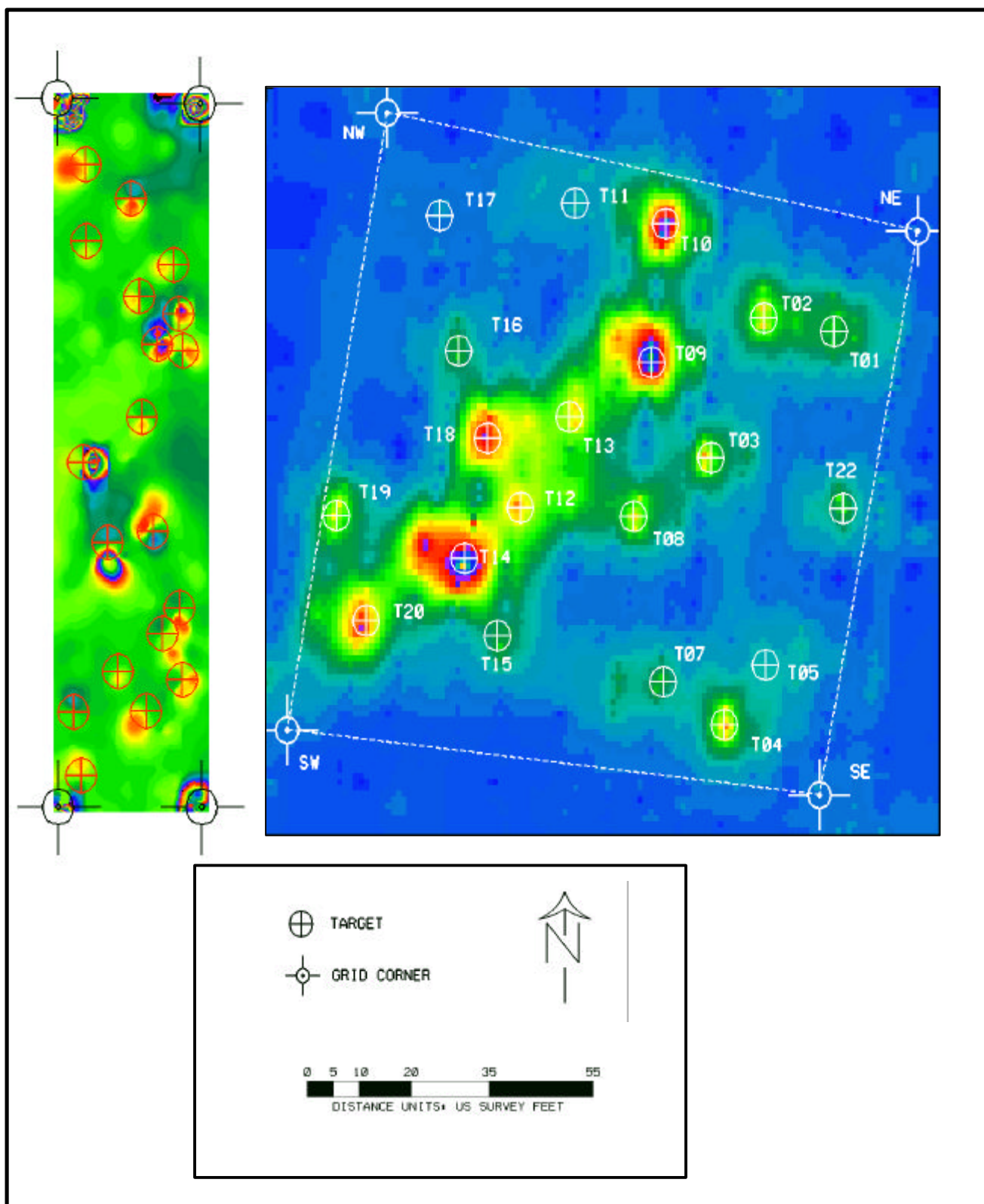


Figure 2. Data from two separate UXO sites where the GPS-integrated FAST methodology was utilized. Data on the left comes from total field magnetometers, and data on the left from electromagnetic sensors.



Figure 3: SC&A's backpack geophysical survey system. Shown is a dual head total field magnetometer system and differential GPS receiver. Frequency-domain EM configurations have also been developed. The identical on-site GPS equipment is used to establish grids, position data, and relocate targets.

A backpack version of the FAST methodology has been developed (Figure 3) for areas not navigable with the FAST cart. This system can navigate with either GPS or fiducial navigation systems, and has been integrated with magnetometers, gradiometers and frequency domain electromagnetic sensors.

4.2 Streamlined Data Processing

After geophysical data are collected, an on-site process system is used to produce same-day QC maps, and next-day geophysical survey maps. The data processing procedure was built for speed, accuracy, and quality control. The entire data flow is standardized, reproducible, objective, and fully documented. All work is performed within a comprehensive geographical information system (Figure 4) that allows for the simultaneous usage of geophysical data, archival planimetric data (air photos, infrastructure maps, etc.), and surface features readily mapped with the on-site GPS. The GIS integration also provides a full suite of coordinate system and cartographic functions.

Geophysical data are processed and analyzed to produce target maps and reports that document the coordinate location, size, and depth of all detected targets. This is accomplished by using standard methods of geophysical analysis as well as SC&A's Ordnance and Explosives Knowledge Base (OE-KB) – a top-ranking geophysical analysis system at the Army's Jefferson Proving Ground that has been used at over 20 UXO sites. Built specifically for UXO applications, this new survey capability allows for safe, accurate, high-quality geophysical surveying at high production rates.

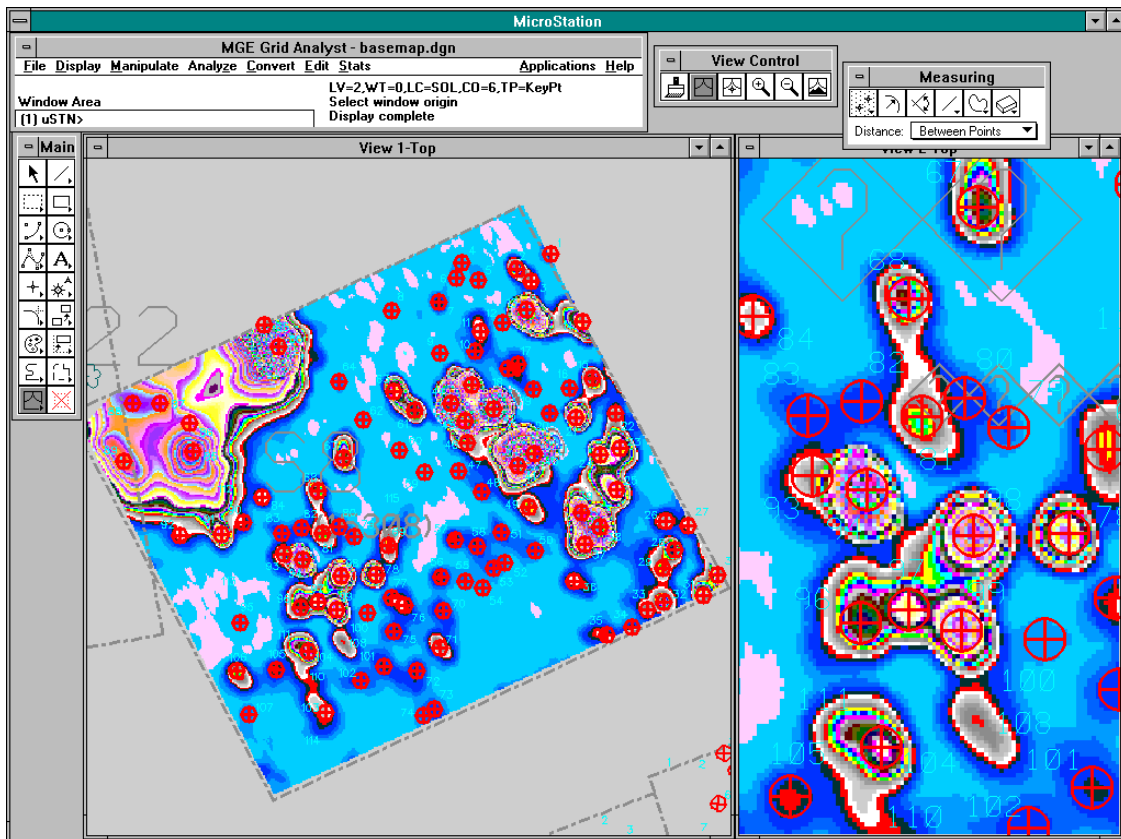


Figure 4. SC&A developed the Ordnance and Explosives Knowledge Base to detect, locate, and characterize UXO. Fully integrated within the Intergraph GIS, the OE-KB has been a top ranked analysis methodology at the Army's Jefferson Proving Ground tests.

4.3 Meeting the Performance Objectives

Based on the performance objectives discussed in Section 3, Table 1 provides a review of the SC&A's FAST methodology.

Table 1. FAST Methodology Performance Approach

Performance Topic	Key Issues	FAST Approach
Data Quality	<ul style="list-style-type: none">❑ High SNR for target detection❑ Variable data density needed	<ul style="list-style-type: none">❑ Ground based cart system❑ Cart constructed of composite materials❑ Flexible sensor configuration
Sensor Deployment Flexibility	<ul style="list-style-type: none">❑ Variable UXO type and distribution❑ Variable site conditions	<ul style="list-style-type: none">❑ Magnetometer and/or electromagnetic configurations❑ Cart and backpack modes
Navigation Technology	<ul style="list-style-type: none">❑ Variable conditions❑ Reliability required	<ul style="list-style-type: none">❑ GPS, tick wheel modes❑ Open architecture allows new technologies
Production Rates	<ul style="list-style-type: none">❑ Wide range of needs❑ Limits on downtime	<ul style="list-style-type: none">❑ Scalable technology 1-1000 acre sites❑ Achieved rate: 70 acres/day❑ Downtime: 0 in last 12 months❑ Mass-produced for redundancy
Safety	<ul style="list-style-type: none">❑ UXO professionals required	<ul style="list-style-type: none">❑ UXO professionals utilized❑ Forward sensors design for UXO avoidance❑ Zero issues in 4,000 acres
Integrated Data Analysis	<ul style="list-style-type: none">❑ Avoid data bottleneck❑ Controlled system❑ Advanced data analysis	<ul style="list-style-type: none">❑ On-site processing❑ Semi-automated processing❑ Fully documented SOPs❑ OE-Knowledge Base❑ Fully integrated within GIS

5.0 Advancements of Developed Technologies

SC&A FAST methodology is a tested and mature system, having surveyed over 4,000 acres in the last year. However, several advancements are being developed to fully meet the optimal performance objectives described in Section 3. These include:

Integrated Field Observations: While the FAST cart or backpack system is being deployed, the survey crews routinely make observations in the field that can significantly assist during the interpretation of the collected and processed data. These include the location of

soil and vegetation changes, locations of surface debris, archeological features, etc. Development is underway to record these observations on-the-fly, without stopping to record GPS locations.

Marine Applications: For some shallow marine environments, the FAST system can be utilized to map shallow UXO. The technology is being modified to allow towing from a surface water platform.

Realtime Detection: An optimal system would detect targets as the system collects the geophysical data. SC&A has begun research and development of a Smart Array System that will allow realtime detection in the field. When fully developed and tested, the system will allow for immediate target marking, increasing productivity and decreasing relocation inaccuracies.